APPLE STORAGE IN THE WENATCHEE-OKANOGAN VALLEY

by

W. V. Hukill, Senior Agricultural Engineer
Bureau of Agricultural Chemistry and Engineering

and

Edwin Smith, Senior Horticulturist
Bureau of Plant Industry

Agricultural Research Administration
UNITED STATES DEPARTMENT OF AGRICULTURE

August 1942

FOREWORD

Among the underlying factors affecting the economic position of the fruit industry in the Wenatchee-Okanogan area, the condition of fruit products as the consumer receives them has been recognized as one of primary importance and one that has not been given sufficient attention in the past. It is obvious that a fresh fruit industry cannot remain stable if its products do not reach the consumers in a fresh and appetizing condition - one that gives satisfaction and stimulates continued demand. The factor of condition is particularly significant with the fruit industry of this area where the reputation of its product is so largely reflected by the consumer estimation of a single apple variety - the Delicious.

If not given proper attention in all phases of harvesting, packing, storing, and distributing, the Delicious apple is especially liable to be in an overripe and unpalatable condition when it reaches the consumer. Apples from this area are too frequently in this condition.

Consideration of this situation caused the Secretary of Agriculture to direct the Bureau of Agricultural Chemistry and Engineering and the Bureau of Plant Industry to investigate the handling and storage of apples in this area. In this preliminary report are included some of the results of this study and recommendations by the investigators. Special attention of growers, shippers and warehousemen at this time is directed to the sections on storage management and operation in view of the present difficulty in making plant alterations or extensions.

by *George Hudson*

George T. Hudson
Special Representative
US Department of Agriculture

APPLE STORAGE IN THE WENATCHEE-OKANOGAN VALLEY
W. V. Hukill, Senior Agricultural Engineer
Bureau of Agricultural Chemistry and Engineering
and
Edwin Smith, Senior Horticulturist, Bureau of Plant Industry
Agricultural Research Administration

C O N T E N T S

STORAGE CAPACITIES

In the spring of 1941 a survey was made of the cold storage in the Wenatchee-Okanogan area. The results were covered in a mimeographed report issued by the Bureaus of Agricultural Chemistry and Engineering, and Plant Industry which indicated the approximate number of boxes that could be held in cold storage in the area and the approximate rate at which boxes could be cooled during harvest. By September 1941 some additional capacity had been provided.

Table I shows the cold storage space for the area as of September 1941, together with the approximate number of boxes of apples packed in 1941 in each district. This does not include the pear crop.

Table I.

COLD STORAGE SPACE IN THE WENATCHEE-OKANOGAN AREA
IN
SEPTEMBER 1941

District	Cold Storage Space		1941 Crop Packed Apple Boxes
	Cars	Boxes	Boxes
Oroville-Ellisford-Tonasket	757	605,000	1,326,000
Omak-Okanogan-Malott	836	669,000	1,440,000
Brewster-Pateros	820	655,000	1,239,000
Chelan-Chelan Falls-Azwell	1,604	1,280,000	2,099,000
Entiat	442	353,000	922,000
Wenatchee-Orondo	3,185	2,540,000	2,186,000
Monitor-Cashmere-Dryden	1,412	1,130,000	2,059,000
Peshastin-Leavenworth	813	650,000	661,000
Total	9,869	7,882,000	11,942,000

About 53 percent of the 1941 crop was of the Delicious variety-- Common and Reds. The percentage varied in the districts from about 40 percent in Wenatchee to about 70 percent in Brewster-Pateros. In any one district the period of Delicious harvest is relatively short, which means that apples are brought into cold storage at a high rate for a short time. The Delicious crop for 1941 and its relation to the daily cooling capacity of the cold storage plants are shown in Table II.

EFFECTS OF COLD STORAGE

CHARACTER OF FRUIT

The need for refrigeration in storing any product arises from the nature of the product. Fresh fruits and vegetables are alive for a time after they are harvested. The length of time they may be preserved for consumption depends upon how quickly the end of life approaches. Generally, the changes taking place are slowed down by low temperatures. Each kind of product and each variety has its own characteristics which determine how long and under what conditions its storage life may be extended. There are differences within each variety which depend upon such things as soil conditions, climate, etc., but by close study of individual varieties fairly

Table II.

RELATION OF COOLING* CAPACITY OF COLD STORAGE PLANTS
TO
NUMBER OF BOXES OF DELICIOUS APPLES IN 1941 CROP

District	1941 Delicious Pack	Daily Cooling Capacity	Days Required To Cool All Delicious	Amount Cooled In 15 Days	Excess not Cooled in 15 Days
	Boxes	Boxes	Days	Boxes	Boxes
Oroville) Ellisford) Tonasket)	896,000	22,000	41	330,000	566,000
Omak) Okanogan) Malott)	604,000	28,800	21	432,000	172,000
Brewster) Pateros)	876,000	25,800	34	387,000	489,000
Chelan) Azwell) Manson)	1,266,000	43,500	29	652,000	614,000
Entiat	460,000	19,700	23	296,000	164,000
Wenatchee) Orondo)	892,000	94,000	9.5	1,410,000	-518,000
Monitor) Cashmere) Dryden)	907,000	47,800	19	717,000	190,000
Peshastin) Leavenworth)	391,000	17,000	23	255,000	136,000
Wenatchee-) Okanogan) Area)	6,292,000	298.600	21	4,479,000	1,813,000
	7880 cars	374 cars		5610 cars	2270 cars

*Cooling from 65° F. to 32° in 7 days.

---

accurate generalizations can be made by which the storage reactions
may be predicted. The rate of ripening in apples and pears speeds
up markedly as soon as the fruit is removed from the tree, provided
there is no lowering of temperature. When picked at optimum maturity
and delayed in refrigeration, the effects on the fruit of this rapid

ripening are not apparent at the time, but will be reflected in a shortened life of the fruit, possibly to be observed after several months in cold storage.

RESPIRATION

As apples or pears ripen, heat is produced. At 32° F. there is sufficient ripening in a carload of apples to emit enough heat to melt about 100 pounds of ice in 24 hours; at 40° the amount of heat is twice as great; at 60° the heat of respiration would melt about 780 pounds of ice in this time. In cooling Delicious apples from 70° to 35° in six days, the amount of heat generated through ripening is almost one-third of the sensible or field heat. If cooled in three days, only about half of this amount of heat of respiration has to be dealt with; but if cooling takes two weeks, the amount is doubled. On account of the heat of respiration, it is necessary to remove heat from apples in cold storage continuously. For this reason, apples at the center of a block may have a temperature several degrees higher than those near the aisle unless provision has been made for the cold air to circulate about the packages.

RIPENING PROCESSES

When an apple is picked it has a capacity for continuing to live. As it ripens, this capacity is used up, and the rate at which it is used up determines how long the fruit will be usable. Ripening has been found to proceed about in proportion to the rate at which respiration takes place. At low temperature the rate of ripening, or of using up the potential life of the apple, is much slower than at higher temperatures. The rate of ripening is at a minimum at temperatures just above the freezing point.

FREEZING TEMPERATURES

Different varieties of fall and winter pears freeze at temperatures ranging from 26.4° F. to 28.8° with an average freezing point of 27.7°. Freezing temperatures for fall and winter varieties of apples range from 27.8° to 29.4° with an average of 28.5°. To permit a margin of safety against freezing, storage temperatures of 30° to 31° are usually recommended for apples, with slightly lower temperatures for pears. Pears may be precooled down to 28°.

FACTORS AFFECTING STORAGE QUALITY OF APPLES

It is a common experience to have apples of a given variety keep better in storage when grown in one locality than when grown in another. Climatic, soil, and tree condition have a direct influence on storage response. Conditions under which a fruit is harvested and packed also are most important.

GROWING CONDITIONS

Apples produced under conditions which result in normal growth and maturity of tree and fruit usually have the best storage quality. It is recognized that where an apple tree makes an abnormal growth

with heavy foliage and is late in maturing its wood, as happens in young orchards or in orchards having abnormal supplies of nitrogen and water, the fruit usually is abnormal in size, texture, and quality. This frequently happens when a tree bears a light crop. After a certain period in the summer, increased size in an apple fruit is more related to growth in size of cells than it is to an increase in the number of cells. Large apples consist of large cells, and small apples consist of small cells with relatively thicker, stronger cell walls. This accounts for the firmer texture in the smaller-sized fruits and for the better storage qualities in fruit grown under conditions contributing thereto.

As apples are received for storage, it is important to keep the identity of those lots coming from trees or orchards where growing conditions are likely to cause poor storage quality so that they may be disposed of promptly.

HARVESTING CONDITIONS

The maturity of apples at harvest has a direct influence on the fruit's keeping quality. When picked before becoming adequately mature or after reaching an advanced stage of maturity, the fruit may be susceptible to storage disorders that might be avoided if harvesting were done at an optimum stage of maturity (see storage disorders). Blue mold decay (Penicillium expansum) is the most serious storage rot in the Pacific Northwest. This is a fungus that most commonly enters apples and pears through injuries. These injuries may take place during picking, hauling, washington, or packing. The causes of the larger injuries are obvious and may be detected and corrected by an observant operator. Spores of fungi are microscopic and can germinate and grow in injuries not seen by the naked eye. For this reason it is important to avoid as much as possible all small bruises because where pressure has been sufficient to cause a small bruise, it possibly has been great enough to cause a microscopic injury in the skin.

Pressure against the side or bottom of an old orchard box is particularly hazardous, because this may result in pressing spores of rot-producing fungi into minute injuries. Old orchard boxes carry great quantities of spores and, unless sterilized before use, are considered a prime source of infection.

The washing process, if not done carefully, frequently contributes to increased decay and shriveling in fruit during storage. When the washing process is sufficiently severe to result in visual injuries, microscopic injuries also probably abound. Aside from a reduction in the washing solution temperature, the use of an abundance of clean rinse water is an important means of preventing washing injuries.

Fewer washing injuries occur with a given washing solution temperature after apples are allowed to remain in cold storage for several weeks after harvest. There are no added risks when apples are washed after being held at 32° F. for several weeks. This is not true where the fruit is held until it becomes ripe.

The washing process may be sufficiently severe to cause skin injuries without seriously affecting the rate of ripening in storage. However, such severe treatments so affect the skin that increased moisture losses and shriveling take place and fruit thus washed is not suitable for long-time storage.

The washing, grading, and packing equipment may be the cause of mechanical injuries and should be given a careful inspection periodically to detect faults that may be responsible for unnecessary skin punctures or bruises.

STORAGE LIFE OF DELICIOUS

Over half the apples from the Wenatchee-Okanogan area are of the Delicious variety. To reach the markets in first class condition, this variety has been found to require prompt cooling and low temperature storage. The storage life of Delicious is directly related to the temperature at which the fruit is kept. There is no indication that temperature fluctuations in themselves have any effect on storage life. That is, it is the level of temperature and the time of exposure to each temperature level that fixes the storage life and abrupt changes in temperature do not shorten the life of the fruit. One exception to this rule is in the incidence of soft scald which under some conditions is induced by sudden cooling to 32°. The accompanying chart (Fig. 1) shows the expected period of storage for Delicious under different temperature conditions. Higher temperatures than those indicated should be allowed for during transportation and distribution when considering storage at the point of origin. The upper section illustrates the effect of continuous exposure to various temperatures, while the lower section illustrates the effect of a few typical cooling rates. In each case it is assumed that exposure to the condition indicated starts immediately after picking. The normal life expectancy of Delicious apples as shown on the chart applies when the fruit is grown on mature, healthy trees, has not been injured in any way, has been picked at the right stage of maturity and is handled and stored under sanitary conditions. Some conditions of growth may result in abnormal fruit which is susceptible to invasion by rot-producing fungi. Usually this may be determined only by the history of the fruit from a given orchard. Fruit from such orchards may not be expected to have a normal storage life.

When Delicious or red strains of Delicious (Starking, Richared, etc.) are picked before becoming adequately mature, they may be susceptible to storage scald to such an extent that their commercial storage life may be cut in half. When picked at an advanced stage of maturity or after watercore has made its appearance, the fruit may become stale in flavor and mealy or develop internal breakdown long before the indicated dates. Although this variety is very responsive to proper handling, it cannot be considered a late keeper. Under the best of storage conditions, it begins to lose its full varietal flavor after January. Although it may be kept crisp and juicy until the spring months, its flavor usually is mild or neutral by late winter when it quickly becomes mealy and stale after being taken to living-room conditions. A delay of a week or ten days in the orchard will often decrease the life of the fruit two or three months. No storage treatment can restore that part of the fruit's life which has been spent.

Figure 1

NORMAL STORAGE LIFE EXPETANCY
DELICIOUS APPLES

FOR CONTINUOUS STORAGE

AT 70°
XXXXX

AT 60°
XXXXXXXX
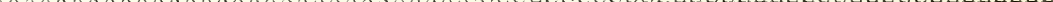
AT 50°
XXXXXXXXXXXXX

AT 40°
XXXXXXXXXXXXXXXXXXXXXXXXXX

AT 36°
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

AT 32°
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

AT 30°
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
' OCTOBER 'NOVEMBER' DECEMBER' JANUARY 'FEBRUARY' MARCH ' APRIL ' MAY ' JUNE

FOR VARIOUS RATES OF COOLING

COOLED TO 30° IN 7 DAYS
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
⟩   JUNE 1

COOLED TO 32° IN 7 DAYS
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                                     APRIL 5) *
COOLED TO 36° IN 7 DAYS; THEN TO 32° IN 4 WEEKS
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                              MARCH 20) *
COOLED TO 40° IN 7 DAYS; THEN TO 21 DAYS AT 40°; THEN TO 32° IN 28 MORE DAYS)
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                        FEBRUARY 10) *

COOLED TO 36° IN 7 DAYS
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                    JANUARY 15

COOLED TO 36° IN 6 WEEKS
XXXXXXXXXXXXXXXXXXXXXXXXXXXX
             DECEMBER 20

(*FOR EACH WEEK OF
(EXPOSURE BEFORE
(STORAGE AT 70°
(DEDUCT 9 WEEKS OF
(STORAGE LIFE; AT
(53° DEDUCT 1 MONTH
(OF STORAGE LIFE.

The storage period covers only one part of the process of handling apples from the tree to the consumer. Cultural conditions, handling during harvest, cooling, storing, transporting, distributing, and treatment in the hands of the consumers, each influences the final quality of the apple. Shortcomings in treatment during any phase, from production to consumption, cannot be overcome by excellence of treatment during any other phase. After picking, the length of life of the fruit depends directly upon the fruit temperature. High temperatures at any time after picking hasten the processes that finally make the apple useless. Whether they occur in the orchard, the warehouse, or a store, the effect depends upon the temperature level and duration of exposure. Responsibility for temperature control and resultant apple condition is not entirely in the hands of the storage operators. It is only because apples are ordinarily in storage longer than they are in the other processes that temperatures in storage have more to do with final condition than those at other times.

OTHER VARIETIES

For most apple varieties other than Delicious, similar relations between temperatures and storage period will apply. There is a considerable variation, however, among varieties in the length of time they will keep at any given temperature. Certain varieties in some areas react unfavorably to temperatures below 36° or 40°, but for the most part, Northwestern apples should be stored at 30° to 31°. One modification of this general rule, as it relates to soft scald, should be mentioned. A low temperature injury known as "soft scald" may be induced by placing susceptible fruit where air temperatures below 36° prevail. Such fruit should not be cooled in air temperatures below 36°. Jonathan apples are especially susceptible. Overmature or ripening Rome Beauty, Golden Delicious, and Winesaps should also receive this consideration. When the latter varieties are not over-mature and are stored immediately after picking, there is little danger from precooling or storing at a temperature of 31°.

STORAGE DISORDERS

"Storage scald" or "superficial scald" is quite generally controlled with oiled wraps, while "soft scald" or "deep scald" is not. The latter occurs with certain apples which are exposed to low temperatures at a certain stage of ripening. When apples are held in an atmosphere of 35 percent CO_2 gas for 24 hours prior to storage, they are made practically immune to soft scald. Soft scald has not been reported in common storage. It rarely occurs at 36°, though the life of the fruit is materially shortened at this temperature as compared to storage at 30° or 31°.

Bitter pit cannot be controlled in cold storage. Most of the fruits that would show the disease if they were allowed to ripen in storage, can be sorted out before storage by permitting the fruit to become mature on the trees.

The three most important storage rots in the Northwest are blue mold rot, gray mold rot, and perennial canker decay. Contamination of

apples by spores of fruit rots takes place largely in the orchard or between the orchard and cold storage. The chance of contamination of packed fruit in cold storage is remote. Contamination of fruit from mold spores carried in the storage air may be reduced somewhat by fumigating the rooms while empty. Sulfur dioxide gas is an effective fumigant, and it is produced cheaply by burning sulfur.

Low temperatures inhibit mold growth. Although the amount of decay may be reduced by good storage temperatures when fruit has been contaminated, decay will not be prevented by perfect storage condition. It is necessary to institute precautionary measures in the orchard and packing shed. These include careful and prompt handling, good picking buckets, clean orchard boxes, frequent cleaning of washing tanks, adequate rinse with uncontaminated water, efficient and sanitary packing equipment, clean packing gloves, and dust reduction in the packing house. It is important that fruit be packed before it becomes ripe.

Skin breaks are the most common places for entry of blue mold spores. Fruit advanced in maturity when picked is most susceptible to entries at lenticels.

Gray mold contamination generally comes from decaying leaves or other vegetation in the orchard, such as alfalfa. Unlike blue mold, it will spread rapidly from one fruit to another through the wraps unless copper impregnated paper, known commercially as the "Hartman Wrap," is used.

Perennial canker decay, commonly called "bull's eye rot," comes from spores originating in cankers on the limbs of apple trees. Rains frequently carry the spores from tree to fruit. Fruit should not be stacked under infected trees. There is no known control after apples become contaminated, but the rot seldom appears before the fruit becomes firm-ripe. Contaminated fruit should be given prompt refrigeration and placed in consumption while still firm. It is a good rule to market such fruit while still classified as "firm."

Internal breakdown of various forms occurs in several varieties. "Jonathan breakdown" occurs in fruit picked at an advanced stage of maturity. Late pickings should be given prompt refrigeration and disposed of at an early date. "Core breakdown" in Delicious frequently occurs in water core tissue. Water core largely disappears in storage, but the tissue is weak so that any variety showing much water core at harvest should not be held for late storage.

Shriveling or wilting takes place to a greater extent in some varieties than in others. Pears or apples harvested before becoming mature are subject to shriveling. Maturity at picking is especially important in avoiding excessive shriveling in storage with some varieties of pears. Removal of wax from the skin by washing apples and pears in wax solvent solutions causes the fruit to be more susceptible to shriveling.

To prevent shriveling in storage it is important to maintain the relative humidity of the storage atmosphere at approximately 85 percent. Packing apples in closed containers and with wrappers reduces the amount of shriveling but will not prevent it if the relative humidity

of the storage air remains below an optimum range for long periods of time. In storages with air circulation systmes the greater the velocity of air passing over the fruit, the more important becomes the necessity of maintaining the relative humidity at 85 percent.

RELATION OF FACILITIES TO FRUIT CONDITION

The effect of prompt cooling and proper holding temperature on the condition of apples is not necessarily reflected in a premium price on well-handled lots. The fact that a lot of fruit handled carelessly may sometimes bring a better price than a lot which has been cooled and stored under best conditions, tends to obscure the real difference in condition. Whether or not improved condition results in an immediate price return, there is no question that the demand for apples over a season or the general price levels over a longer period are based on consumer experience with apples from this area.

Most of the storages in the area handle more Delicious than can be cooled promptly. In order to determine whether this overloading has an effect on condition, inspection certificates were examined on shipments from a number of plants as the 1941-42 season progressed. One of these plants had cooling capacity sufficient to cool the Delicious promptly to 32° F. as fast as they came in, while others located in the same district were overloaded at harvest time. All certificates from the one house were included in one group, and those representing shipments at about the same dates from the other houses were included in another group. These were from storages with varying degrees of overloading. In shipments up to November 1, there was no noticeable difference in condition between the two groups. On November and December shipments, certificates from the first group were noticeably superior. There were 41 certificates from the one house in January and 43 in the other group. All 41 had less than 1 percent decay, and there were no notations of any ripe apples. Of the 43, 13 showed 1 percent or more decay, including 6 having some lots ranging to 8 percent or more; 10 showed at least a few ripe apples. The difference between the groups increased as the season progressed. From late February through April 2, 12 certificates were found from the one house and 23 examined from the others. In the first group, only one showed as much as 1 percent decay, while of the second group, 16 had lots with 1 percent or more, including 7 with a "range of decay"[1] or some lots removed from the shipment for reconditioning after inspection.

This comparison indicates only the difference between the groups at shipping point. It does not show what the difference may have been after the subsequent period of transportation and market handling. The plants from which the above certificates were obtained were not in one of the districts having the greatest deficiency in cooling capacity. They represented perhaps average degrees of overloading. It is obvious that without adequate cooling facilities, the general level of fruit condition and consumer satisfaction cannot be expected to command maximum returns from the crop. It is also clear that for

[1] "Range of decay" is a term used to describe lots having boxes with over 5% decay.

the duration of the war, little material will be available for relieving the deficiency in cooling capacity. If substantial gains are to be made in the condition of fruit delivered from the area, they will have to come largely from improved handling and operating practices which permit the limited cooling capacity of the area to be used to best advantage.

REFRIGERATION

FAMILIARITY WITH PROCESSES

The best way to become familiar with refrigeration is to work with it and use it. Each cold storage plant has characteristics of its own which require familiarity with that particular plant to permit taking advantage of its good points and to avoid difficulties that may not be common to other plants. However, general principles of refrigeration apply to all plants, and familiarity with them will enable an operator to take better advantage of his experience. These are covered in text books, and more specific information such as refrigerant characteristics, insulation values, fan and duct data, requirements of stored products, condenser, compressor, and evaporator characteristics, cooling surface, power requirements, etc., is given in handbooks. A few references are listed in the appendix.

PUMPING HEAT

The process of refrigeration might be likened to pumping air out of a tank to a pressure lower than that of the atmosphere. Once the desired low pressure inside the tank is reached, the only additional pumping necessary is to remove the air entering the tank by leakage and the amount of pumping will depend entirely upon the amount of leakage.

In the case of a refrigerated space, it is desired to maintain a certain temperature below that of the surroundings. Heat is pumped out until the desired low temperature is reached whereupon further pumping is necessary only to remove the heat that enters the chamber by leakage through walls and open doors or that which is generated within the space.

When pumping air from a vacuum tank, if only a slight degree of vacuum is required, less power is needed; and a smaller pump will suffice than where a high vacuum is required. The size of the pump required and the horsepower of the motor depend upon two factors: (1) the amount of air to be removed and (2) the pressure inside the tank. If too much air is allowed to enter the tank, the pump cannot remove it, and the desired vacuum cannot be maintained. Similarly in a refrigerating system, if only a moderately low temperature is required, less power and a smaller compressor are needed than where a very low temperature is desired. Furthermore, if the refrigeration machinery does not have the capacity to pump out the heat as fast as it enters the chamber, the desired low temperature cannot be maintained.

In extending the comparison, the factors determining the size of the pumps are, in the case of the vacuum, (1) pressures, usually expressed

in pounds per square inch, and (2) amount of air, expressed as pounds
per minute. In the refrigerating system the factors are: (1) Tempera-
ture expressed in degrees, and (2) amount of heat, commonly expressed
as "Btu's." The term, "Btu," (the amount of heat required to raise
the temperature of 1 pound of water 1° Fahrenheit) corresponds to the
term "pound" inasmuch as they both express definite quantities of the
thing to be handled.

QUANTITY OF HEAT

Btu may be an unfamiliar term, but in dealing with refrigeration prob-
lems, it is just as necessary to consider the quantity of heat to be
handled as it is to speak of pounds of air or gallons of water when
computing the necessary sizes of air or water pumps for given jobs.
One pound represents a very definite and measurable amount of air, and
it is still the same amount of air regardless of the pressure under
which it is placed. Likewise, one Btu represents a definite and meas-
urable amount of heat, and it remains the same amount of heat regard-
less of the existing temperatures.

The refrigeration demand upon the machinery frequently is spoken of in
terms of "tons." This had its origin through a comparison of refrigera-
ting capacity, or demand, with the amount of refrigeration secured from
melting 1 ton of ice. As it requires 144 Btu's of heat to change 1
pound of ice to water at the melting point, 288,000 Btu's are required
to melt 1 ton of ice. Where it is necessary to remove 288,000 Btu's
of heat in 24 hours, 1 ton of refrigeration is required.

If, in a storage building, a temperature of 32° Fahrenheit, is to be
maintained, for example, the refrigeration system will have to remove
an amount of heat just equal to the amount which enters the building.
The heat entering may come from a number of sources. In the first
place, if the outside temperature is above 32°, some heat will come
in through the walls. This amount can be reduced by insulation, but
no amount of insulation will exclude all heat leakage. If there are
cracks in the building, or if doors or windows are open and permit
warm outside air to enter, a second quantity of heat will be introduced,
the amount depending upon the temperature and quantity of air. If
materials having temperatures above 32° are placed in the cooled space,
they will introduce still another quantity of heat, the amount depend-
ing on the temperature, the weight, and the nature of the material. If
the materials are living, as for example, apples, they will produce
heat continually; and this heat is in addition to that which they con-
tained when first put in the storage. The heat from all of these
sources and from other incidental sources, combines into a quantity of
heat which the refrigerating system must remove. If the system has
sufficient capacity it can all be pumped out. If the amount of heat
introduced into or produced within the building exceeds the capacity
of the refrigeration system, some of it will remain in the fruit and
cannot be taken out until the rate of heat intake into the building
has dropped below the rate at which it can be removed.

The amount of heat that a refrigeration system can remove may be in-
creased or decreased by the conditions under which it operates, but it

will be seen that no manipulation of air movement or special stacking
of boxes or other adjustment can prevent the accumulation of heat if
it is being introduced faster than it is being removed.

THREE STEPS IN THE REFRIGERATING PROCESS

Heat, like air, is handled in definite quantities; but, unlike air, it
cannot be moved bodily from one point to another. By its nature it
moves from a position of high temperature to one of low temperature.
A refrigerating system, or heat pump, must take advantage of the ten-
dency that heat has to move from high to low temperature. Heat moves
from the storage room through the cooling coils to the ammonia which is
at a lower temperature. The compressor takes this heat and changes it
to a condition of much higher temperature. (Just how this rise in
temperature level is accomplished need not be considered for the present
discussion.) The heat is then permitted to move into the condenser cool-
ing water, here again taking advantage of its tendency to move from a
condition of high temperature (the compressed ammonia) to one of lower
temperature (the cooling water).

THREE PARTS OF REFRIGERATING SYSTEM

The above three steps in heat removal are accomplished by the three
essential parts of the refrigerating system. The heat is removed from
the room by the evaporator either in the form of direct expansion pipes
or coils over which air is blown. It is changed to higher temperature
heat by the compressor. It is finally discharged to the cooling water
by the condenser. Since all the heat removed must pass in turn through
each of these three parts, the capacity of each part needs to be suffi-
cient to transfer all the heat.

In the evaporator or cooling coils, the amount of heat picked up de-
pends upon (1) the temperature difference between the refrigerant
(ammonia) in the coils and the air outside the coils, (2) the amount
of coil surface exposed and (3) the resistance to heat flow through
the pipes. The resistance to passage of heat into the coil in turn
depends not only upon the cleanness of the coil but also upon the velo-
city of air past the coil and the velocity of the refrigerant (whether
liquid or vapor). Accumulated frost may greatly increase the resist-
ance is increased by an accumulation of frost, or if there is not enough
piping surface exposed, it will take a large temperature difference be-
tween the inside and outside of the coil to permit sufficient heat to
pass into the coils. This means a low ammonia temperature. It is the
work of the compressor to boost the temperature of the ammonia to such
a point that heat will flow from it into the condenser water. If, due
to high resistance or insufficient surface in the cooling coils it is
necessary to maintain a low ammonia temperature (which means low suction
pressure), the compressor is forced to boost the temperature from a low
point, and it cannot handle as much heat as if the suction temperature
were higher.

The compressor must also discharge the ammonia at such a temperature
that heat will flow from it to the cooling water in the condenser. In

general a compressor can handle more heat if the temperature in the
cooling coils is kept as high as possible and the temperature in the
condenser as low as possible. The same conditions also reduce the
amount of power used in removing a given amount of heat.

When the ammonia enters the condenser, heat passes from it into the
cooling water. As in the evaporating coils the amount of heat passing
from the ammonia to the cooling water depends upon (1) the temperature
difference between the ammonia and the water, (2) the amount of surface
exposed, and (3) the resistance to heat flow through the condenser pipes.
Here also, the resistance to passage of heat depends upon the water velo-
city, the ammonia velocity, and the cleanness of the coil. Scale, which
tends to collect on the pipes from the cooling water, may increase the
resistance markedly. If this scale is permitted to build up or if there
is not sufficient cooling surface, the required quantity of heat can
only be transferred to the water by having a large temperature difference
between ammonia and water. As pointed out before, the high ammonia
temperature means reduced compressor capacity and high power consumption.
An adequate supply of water as cold as possible will contribute toward
a low ammonia temperature in the condenser and therefore low power con-
sumption.

CONDENSER

The condenser has one purpose. It must permit the passage of heat from
the compressed ammonia to the cooling water (or air in an atmospheric
condenser) and do so at as low an ammonia temperature as possible. It
must pass on all the heat which has been taken up in the evaporator,
and in addition, the heat which has been added by the work of the com-
pressor. The passage of heat into the cooling water is facilitated by
a large amount of cooling surface, by a large quantity of cooling water,
by a low water temperature, by a high velocity of water and of ammonia
past the surface. A high ammonia temperature also increases the amount
of heat transferred to the cooling water, but it is the duty of the con-
denser to receive and discharge the ammonia at as low a temperature as
possible. The design of the condenser and its operation should be such
as to remove the required amount of heat without excessive ammonia
temperatures.

In operation, the effectiveness of the condenser may be judged by the
head pressure indicated on the gage. If the head pressure goes too
high, the effects on the system are that less heat can be removed from
the cold rooms and more power is required to operate the compressor.
The effect of various high head pressures on power requirements at
various suction pressures may be seen in the accompanying chart, Figure
2. For example, the chart shows that operating at 25-pound suction
pressure, if the head pressure is 120 pounds, about 1.0 horsepower is
required to remove 288,000 Btu per day (1 ton of refrigeration) whereas,
at a head pressure of 195 pounds, about 1.5 horsepower is required for
removing heat at the same rate. That is, the power cost is about 50
percent higher at a 195-pound head pressure than at 120 pounds. At the
same time, a high head pressure results in reducing the amount of heat
that the system can handle. This is illustrated in Figure 3.

FIGURE 2
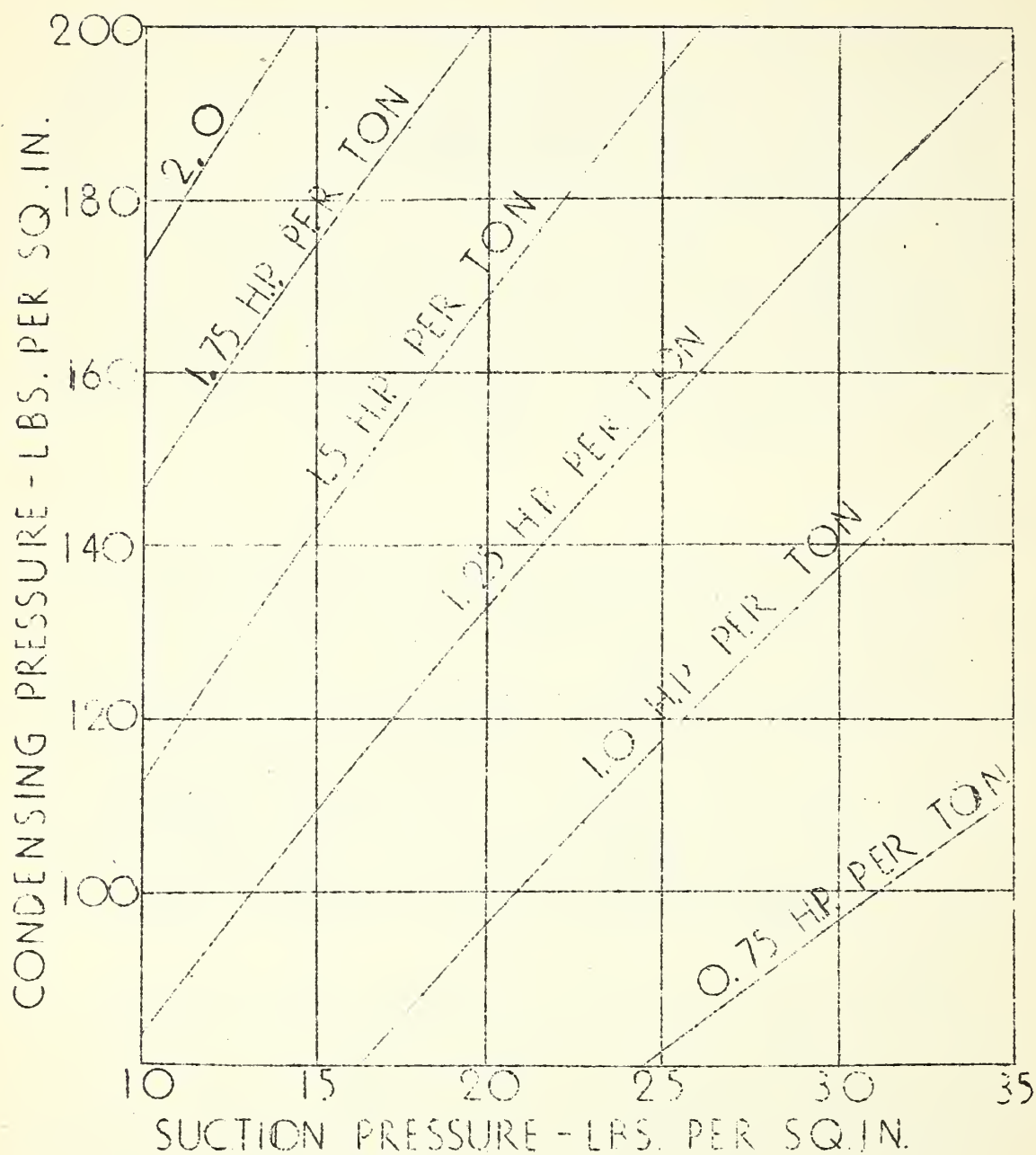
EFFECT OF OPERATING PRESSURES UPON POWER
REQUIREMENTS OF A TYPICAL AMMONIA
COMPRESSOR.

FIGURE 3
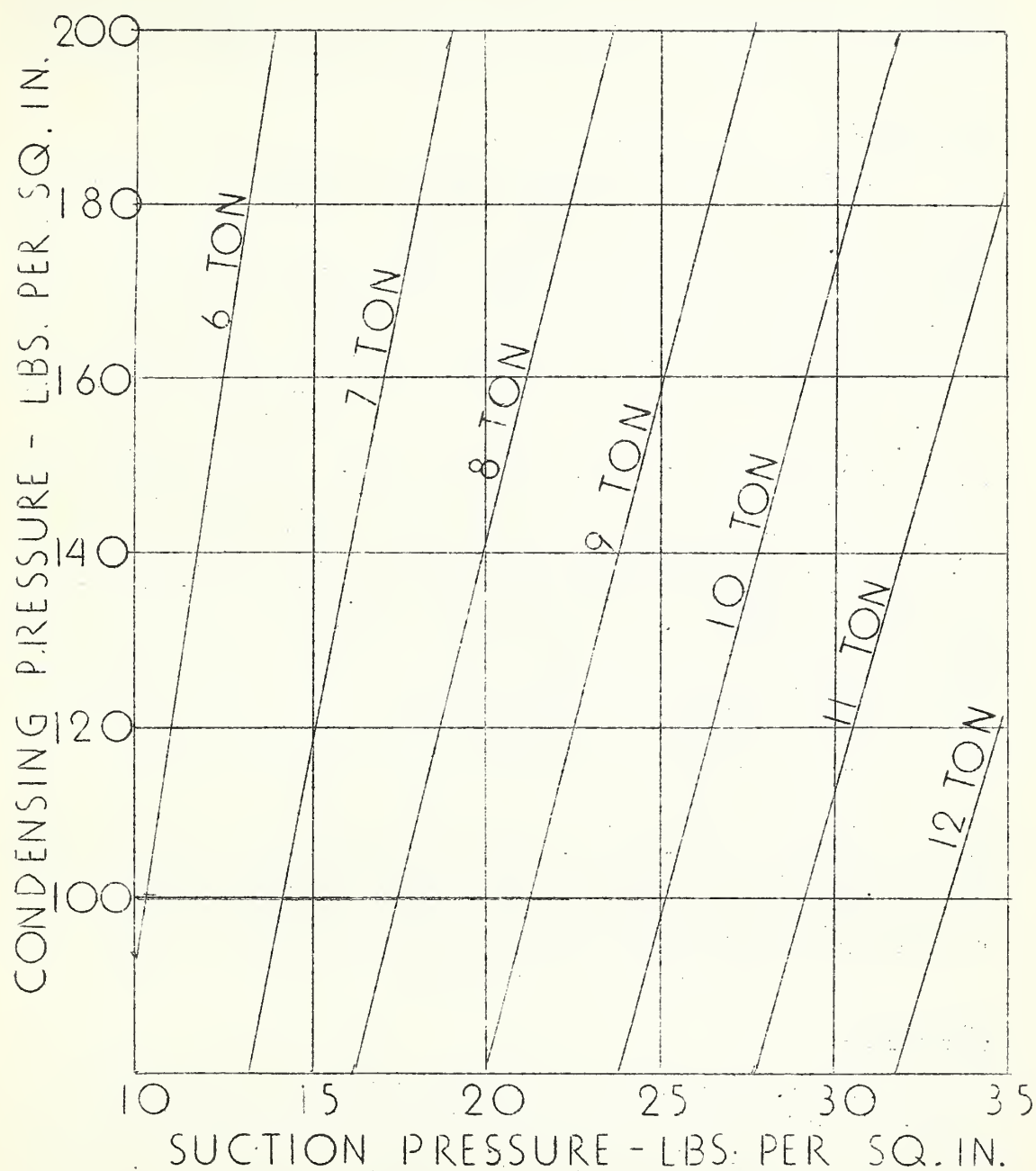
EFFECT OF CONDENSING AND SUCTION.
PRESSURES UPON CAPACITY OF A TYPICAL
AMMONIA COMPRESSOR.

If the head pressure is too high when the plant is running to capacity, it may be because of too small a condenser, not enough cooling water, cooling water too warm, presence of non-condensible gases, or dirty condenser tubes. The water used in the condenser contains impurities which corrode the pipes and form deposits on them. This deposit interferes seriously with exchange of heat if it is allowed to accumulate over long periods.

COMPRESSOR

The compressor, by pumping ammonia from the evaporator to the condenser, takes the heat which has been absorbed in the coils and by raising the temperature, allows the heat to be carried away by the condenser cooling water. The rate of heat removal by a given ammonia compressor running at a given speed depends only upon the head pressure and the suction pressure at which it operates, the higher the suction pressure and the lower the head pressure, the more heat will be removed. If the speed is increased, the rate of heat removal will increase proportionately, provided the pressures are maintained the same. It is good practice therefore to operate a compressor at as high a speed as its design will permit during the season when warm fruit is being received. In fruit storage, the demand on the refrigerating equipment is at a maximum for only a short period in the fall. Much of the capacity of this equipment is idle during the rest of the year. In order to get the most out of it for this period while keeping the investment in equipment to a minimum, it is sometimes economical to operate at higher speeds than would be advisable for year round operation. However, compressors should be speeded up only after consulting the manufacturer's representative regarding the particular machine. Greater capacity may be obtainable in some slow speed compressors by changing the valves and lubrication systems to permit considerably higher speeds.

It is a mistake to judge the capacity of a refrigerating system by the power of the motor installed to drive the compressor. For comparative purposes, capacity is sometimes expressed as standard tons, that is, the capacity of 155-pound head pressure and 20-pound suction pressure, for example; but the actual capacity will depend upon the whole system and not on the compressor or on the compressor and motor alone.

EVAPORATOR

The evaporator, or cooling coils, absorbs the heat from the room. The ammonia having had its load of heat removed in the condenser, is expanded to a vapor. This expansion, or evaporation, reduces the ammonia temperature to such a point that it is ready to pick up more heat from the cold room. This is done by direct expansion coils in the room or by air circulated from the room to a bank of coils or finned surfaces. Here, as in the condenser, conditions should be such as to permit the heat to flow with as little temperature difference as possible between the ammonia and the air in the room. If there is not sufficient cooling surface or the surface is covered with frost or if other factors retard the heat flow, the ammonia must be extremely cold. This means a low suction pressure which reduces the capacity of the compressor. At low pressures the ammonia gas is less dense, and a smaller quantity

of gas is drawn into the compressor at each stroke, resulting in a lower refrigerating capacity. Figure 3 shows the effect of various pressures upon the capacity of a typical compressor. It will be seen that the capacity is increased markedly as the suction pressure is raised. For example, at 140-pound head pressure the compressor illustrated delivers 9 tons at a suction pressure of 24 pounds. An increase of 4 pounds in suction pressure changes the capacity of the same machine to 10 tons. If by increased cooling surface or careful operation the pressure could be increased to 36 pounds, about 12 tons of refrigeration would be obtained, a gain of 25 percent. Similar changes in suction pressure in an ammonia machine of any size would result in approximately the same percentage increase in capacity.

Another disadvantage of operating at low suction pressures is that the coils are extremely cold, and a large amount of moisture is condensed out of the air, resulting in low storage humidity. Ample evaporator coil surface will permit the cooling to be done without excessively cooling the air. The result of cooling the air to low temperatures is shown in the appendix.

COLD STORAGE ROOMS

In direct expansion rooms, that is, where cold ammonia is circulated in exposed pipes within the rooms, the fruit is cooled by air which is cooled by the pipe coils. The coils are in the upper part of the room. Air in contact with the coils becomes cold, and cold air being denser than warm air, moves downward. As it picks up heat from the fruit it warms up and again rises to the pipes to be cooled. This circulation caused by differences in air temperatures is called convection. Air velocities in convection currents are relatively low. If the pipes are well distributed over the ceiling of a room and these low-velocity air movements are taking place in all parts of the room, fairly fast cooling can be obtained. On account of the problem of disposing of frost or water condensed on the pipes, they are usually put in groups or banks, and gutters for catching the drip are hung under them. In rooms where large areas of the ceiling are without coils, direct expansion alone cannot cool the fruit very promptly, and there may be fairly large temperature differences between various parts of the room, even after the fruit has cooled to its final temperature. In this case, either portable or permanent fans operating in the room stimulate air movement and tend to improve the temperature distribution. If fans can be installed to give a positive air movement even better results may be obtained. Fans blowing directly over the cooling pipes may be effective in reducing condensation and limiting local freezing in the fruit.

In the dry coil bunker system of cooling, the ammonia coils are put in a separate room or bunker and air from a large blower is passed over the coils then distributed through ducts to the storage room. If large quantities of air are used, prompt cooling and even temperatures may be obtained. The problem of accumulation of frost on the pipes remains, although disposal of the water and frost without damage to the fruit is simpler than with direct expansion. In some installations the pipes are defrosted periodically by spraying them with brine or warm unsalted water. The blower is stopped while the defrosting is taking place. In

other plants defrosting is done by pumping hot ammonia into the coils.
Dry coil bunkers have largely given way to brine spary systems in
recent installations.

In the brine spray system of cooling, air from a large blower is moved
over banks of ammonia coils which are continually being sprayed with a
solution of salt in water. The salt prevents accumulation of frost,
and the fine spray, being in intimate contact with the air, cools it
effectively. A far smaller bank of pipes can be used than in a dry
bunker and cooling can be done with a higher ammonia temperature. Af-
ter cooling, the air is distributed to the storage rooms. When a con-
tinuous brine spray is used, it is necessary to use baffles or elimina-
tors in the air stream to prevent particles of brine from being carried
in the air to the storage rooms. It is also necessary to treat the
brine with chemicals as recommended by equipment manufacturers to re-
duce its tendency to become unduly corrosive. In spite of the necessity
for eliminators which increase the resistance to air flow, and the
tendency of the brine to cause corrosion, brine spray chambers are dis-
placing both direct expansion and dry bunker systems in this area.

A modification of the dry coil or brine spray bunker is the unit cooler.
These coolers contain extended surface coils and blowers for moving the
air through the coils and discharging it to the room. Some are defrost-
ed by a continuous brine spray and in some the coils are washed periodi-
cally with fresh water to remove the frost. These units usually dis-
charge air at the top, either into ducts or through nozzles, and return
it to the coils through openings near the floor. With the return air
picked up in the lower part of the room, it is difficult to get the
best distribution of temperatures. When defrosting is intermittent, it
is important to make the cycle short enough to keep the coils fairly
free from frost. A thin layer of frost interferes with heat transfer
just as with the other types of coils and on account of the close spac-
ing of the cooling surface, frost also reduces the amount of air circu-
lated.

The humidity or moisture content of the air in a storage room depends
largely upon the temperature to which the air is cooled in contact
with the pipes or the brine.

If the doors are left open in warm weather, the warm air entering the
storage may be a source of moisture, but the frost on the pipes or the
overflow in the brine tank is largely from water evaporated from the
fruit. It is desirable to keep this evaporation to a minimum by main-
taining a relative humidity of approximately 85%. This may be done by
limiting the amount of water picked up on the coils or in the spray.
A certain amount of water in the form of gas or vapor is contained with
the air. The lower the temperature, the less the vapor that can be
held. As the temperature of the air drops, a point is finally reached
at which some of the water can no longer exist as vapor and it condenses
to form water or frost. The greater the temperature drop, the greater
the consequent condensation. It is therefore important to operate with-
out reducing the air temperature lower than is necessary. In an air
circulation system, this is done by using large quantities of air and
plenty of cooling surface. If too little air is used, its temperature
must be reduced greatly and excessive condensation will occur. In a

direct expansion system if there is not enough coil surface, the pipes
will have to be extremely cold and the air coming in contact with them
will lose a large part of its moisture. Contrary to common belief, a
brine spray, when used for cooling, does not add humidity to the air.
On the other hand it tends to pick up moisture from the air. That is
why some of the brine must be drained off occasionally and more salt
added. If a brine spray system results in higher humidity than a direct
expansion or dry bunker system, it is because it removes less moisture
and not because it adds more. It removes less moisture because the
surfaces with which the air comes in contact are not so cold.

In all plants there is necessarily a variation of temperature in differ-
ent parts of the room. This variation should be kept to a minimum. The
equalization of temperature in all parts of the room depends almost en-
tirely on circulation of air, either by convection or by forced draft.
Convection cannot be depended upon for adequate circulation unless the
whole ceiling area is flooded with cold air or provided with cooling
coils.

As the air circulates in a storage room, it picks up heat, thereby
raising its temperature. If it is not picking up heat, it is not doing
any good. The air returning to the brine spray or dry bunker is there-
fore warmer than that entering the room from the delivery ducts. The
difference in temperature between the delivery and return is often
referred to as the "split." The amount of the split is directly re-
lated to the amount of air circulated and the amount of heat picked up
in the room. If the split is too large, the only way to reduce it with-
out cutting down the amount of heat picked up is to increase the volume
of air circulated. It cannot be done by making adjustments of openings
unless the adjustments result in greater volume of air. For each ton
of refrigeration used, an air volume of 1,000 cubic feet per minute
(CFM) results in a split of about 10°. (If water is being evaporated
from the fruit and condensed by the coils, this relation is modified
somewhat.) This relation applies to any combination of refrigeration
being done, and volume of air, and resulting split. For example, if
1,000 CFM of air is used in picking up the heat equivalent to 2 tons
of refrigeration, the split will be about 20°, or if 2,000 CFM gives a
split of 5°, about 1 ton of refrigeration is being supplied. It is
customary to design air circulation systems so as to provide for about
1,000 CFM per ton of refrigeration capacity. For example, a 25-ton
plant would circulate about 25,000 CFM. This gives a split of about
10° when the machinery is working to full capacity. After the fruit
has been cooled and some of the compressors are shut off or slowed down,
the same volume of air will result in a lower split. When the refrigera-
tion load is down to 5 tons and if 25,000 CFM is still used, a split of
about 2° will result. In this case, a variation of at least 2° may be
expected in the fruit temperatures in different parts of the room. With
less air volume the variation will be greater.

If fruit were not living and generating a small amount of heat continu-
ously, the problem of holding it at a uniform temperature would be much
simpler. The heat generated must be given up to the air to prevent a
rise in fruit temperature. In order to pick up this heat, the air must
be slightly colder than the fruit and in picking up the heat the air
temperature is raised slightly. For this reason it is not possible to

have the same air or fruit temperature in all parts of a storage room. In some rooms the variation may be kept down to a fraction of a degree while in others it may be difficult to avoid a variation of several degrees even after the fruit has been cooled to its final temperature.

On account of these variations in temperature, readings from a single thermometer in a room may be misleading. In order to operate a plant to best advantage it is desirable to know at least the highest and lowest temperature in each room. It is the core temperature of the fruit itself which determines how well it will keep. It is sometimes difficult to take fruit temperatures in the parts of the room that are likely to be warm. However, there are times during the season, as fruit is shifted or loaded out, when it is possible. In many cases, if temperature conditions are known, steps can be taken to improve the distribution. If actual fruit temperature readings are not taken, there is a tendency to assume that the aisle thermometer shows a room temperature which prevails at all points. This is not the case and large temperature variations may occur, especially for the first few weeks of storage.

The storage season may be divided into two distinct periods--the first period is during the harvest when warm fruit is being put into the plant and the principal problem is cooling the fruit or removing the field heat. The second is the holding period when the main problem is maintaining low temperatures as uniformly as possible. The heat load during this period is relatively low, consisting of the respiration heat generated by the fruit, the heat entering through the walls, and heat from incidental sources such as workmen, power equipment, lights, and entrance of air from outside.

SOURCES OF HEAT

A discussion of the various sources of heat to be removed by a refrigeration system is necessarily more or less technical and includes terms which may not be familiar. It is not difficult to follow, however, when it is kept in mind that heat is just as real as air or water. It can be moved from one place to another, but it cannot vanish completely. If heat is taken from one place, the same amount must show up somewhere else. For this reason it is convenient to think of units of heat as quantities which have a definite meaning, just as we think of gallons of water. A convenient amount of heat is the Btu (British thermal unit). It is the amount necessary to raise the temperature of 1 pound of water 1° Fahrenheit. The important thing to keep in mind is that a Btu is a definite amount of heat that can be pushed around or divided up, but still exists somewhere.

A refrigerating system is capable of taking a certain amount of heat from the evaporating coils and discharging it to the condenser cooling water. One-ton machines can take up 288,000 Btu every 24 hours by operating continuously, or a 10-ton machine can take ten times this amount. The capacity of the cooling system required for a given job depends upon how much heat must be removed each day. In apple storage this heat comes from several sources, each of which can be considered separately. The total load is the sum of the heat from all sources.

FIELD HEAT

Fruit, when placed in storage, is ordinarily a temperature higher than that desired in storage. The heat to be removed in reducing the fruit temperature is called field heat. It takes about .9 Btu to change the temperature of 1 pound of apples by 1°. If the temperature must be reduced from 65° to 32°, for example, the change is 33° and for every pound of apples 29.7 (.9 x 33) Btu must be removed. On the assumption that a box of apples weighs 50 pounds, every box cooled from 65° to 32° requires the removal of 1,485 (29.7 x 50) Btu. If 1,000 boxes are put into storage, under these conditions, 1,485,000 Btu of field heat are introduced into the storage room. If the fruit is cooler or warmer, the heat load will be correspondingly less or greater.

HEAT OF RESPIRATION

Fruit continues to live as long as it is fit for food and is therefore continually generating heat by breaking down some of its constituent materials. The rate at which this heat is generated depends upon the fruit temperature. At 32° a box of Delicious apples gives off about 20 Btu each day. At 60° the figure is seven or eight times as great. Prompt cooling, therefore, reduces the total amount of heat to be removed from a storage room. It is estimated that if fruit is cooled from 65° to 35° in a week, the heat of respiration from a packed box of apples during this period will amount to about 500 Btu, or for 1,000 boxes the heat load would be 500,000 Btu, or about a third as much as the field heat load. If cooling is so slow that it takes two weeks to reach 35 degrees, another 500,000 Btu will have been generated. Even after the apples are cooled to 32°, they continue to give off heat. Each 1,000 boxes generates about 20,000 Btu per day at this temperature. Thus, 1 ton of refrigeration (removal of 288,000 Btu per day) will take care of the heat from about 14,000 or 15,000 boxes after they are cooled down.

INCIDENTAL HEAT SOURCES

In addition to the fruit itself, other sources generating heat are any men, motors, and lights. It might be assumed that each workman gives off 1,000 Btu per hour. The heat from motors can be estimated at 2,500 Btu per hour for each horsepower. If a motor is actually delivering its rated horsepower, the total heat given off will be somewhat greater. Each 100 watt light burning adds about 350 Btu per hour.

AIR INFILTRATION

There are always times when it is necessary to leave outside doors or conveyor plugs open, and in some rooms doors are open almost continuously during the harvest season. Outside air entering the cold room may carry in large amounts of heat. It is impossible to estimate very accurately the heat load added by infiltration of air under ordinary conditions. If we assume that a draft of 200 feet per minute is leaving a cold room at 35° through the lower half of a door 4 feet wide and 7 feet high, and an equal current of dry warm air at 65° is entering the upper half, an estimate of the entering heat can be made; 200 feet

per minute is about $2\frac{1}{4}$ miles per hour and is not a very noticeable
velocity. However, under these conditions, 100,000 Btu per hour
would enter through the open door. If the air were not very dry the
amount would be even more. It would keep an 8-ton machine busy just
to remove this heat. Actually it is next to impossible to keep the
room temperatures down with the door open continually; the air leav-
ing the room is considerably warmer than 35°, and the loss of refrig-
eration may not be as large as this estimate. At best, open doors
cause a large entrance of heat or loss of refrigeration and prevent
holding low temperatures in the room. For this reason it is desirable
to use small openings covered with canvas flaps for loading cold stor-
age rooms. When it is necessary to use hand trucks and keep full-size
doors open, light swinging doors which close after each truck has passed
will reduce the loss of refrigeration.

HEAT PASSING THROUGH INSULATION

Even when there is no infiltration of air through doors, window, or
cracks, there is an unavoidable entrance of heat through the walls,
floor, and roof when the outside of these surfaces are warmer than
the inside. The amount of heat entering through the walls may be re-
duced by insulation which slows the passage of heat by resisting its
flow. The amount of resistance depends upon the character of the in-
sulating material and its thickness. Perhpas the most convenient com-
parison of the effectiveness of various insulating materials can be
made by showing thicknesses which will pass equal amounts of heat un-
der similar conditions. In many cold storages, 12 inches of shavings
are used for insulating the walls. Table III shows the thickness of
various materials required to equal the resistance of 12 inches of
shavings. The thicknesses shown are based on the conductivities pub-
lished in the American Society of Refrigeration Engineers, Refrigera-
tion Data Book.

Table III

RELATIVE HEAT RESISTANCE OF VARIOUS MATERIALS

Material	Thickness Equivalent to 12 Inches of Mill Shavings
Planer shavings	8.74 lb. per cu. ft.-12 inches
Corkboard	$8\frac{1}{2}$ inches
Redwood bark fibre	5.04 lb. per cu. ft.- $7\frac{1}{2}$ inches
Celotex	$9\frac{1}{4}$ inches
Pumice gravel (Grains 1/33 in. to 3/16 in. diam.)	18.8 lb. per cu. ft.-19 inches
Fir, across grain	.29 inches
Concrete	156 inches
Cinder concrete	72 inches

The amount of heat passing through a wall with 12 inches of dry shav-
ings depends upon the temperature difference between the two sides.
When it is 65° F. outside and 32° inside, each 100 square foot of such
a wall may be expected to permit passage of about 2,600 Btu per day.
That is, 11,000 square feet of such a wall will permit the loss of

about 1 ton of refrigeration. Approximately the same amount would be passed by equal areas of the various materials shown in the table if they were of the thickness shown. For walls twice as thick, the heat flow would be only half as great; or for a wall only one-third the thickness shown, three times as much heat would pass through.

It should be pointed out that for fill insulation, such as shavings, sawdust, and redwood bark fiber, the resistance is influenced by the density of packing. In vertical walls, especially, such materials need to be packed in tightly enough so that settling does not occur and leave unfilled spaces after the wall is closed up. In the above comparisons of various materials it is assumed that they are dry. Moisture in all these materials reduces their effectiveness and will cause some of them to rot. They should all be installed so that they will not accumulate moisture. There is a tendency for moisture to condensé on surfaces cooler than the air but not on those warmer than the air. The insulation material in a wall or roof is usually colder than the outside air. It is therefore important for the insulation to be protected against the outside air by a barrier against water vapor, such as coatings of asphalt or vapor-proof paper. A barrier is usually not necessary on the inside of the wall since there is seldom a tendency for a wall to pick up moisture from the inner or cold side. In fact any moisture that may be present in the wall will tend to evaporate from the wall and condense on the cooling coils in the room. For this reason, a vapor barrier on the inside or cold side of an insulated wall may do more harm than good.

PRECOOLING

Precooling is usually spoken of as a special process for the rapid removal of heat from a commodity before transportation. The term is also used in the Pacific Northwest to denote heat removal preliminary to stacking in storage. In precooling winter pears before stacking in storage, usually the fruit is packed, but with apples it is more often done while the fruit is loose in field boxes. For hard varieties, such as Winesaps, such special stacking for precooling is not often used. For softer varieties, especially Delicious, the importance of prompt cooling is being recognized more and more; and arrangements for precooling are being installed in an increasing number of plants as fast as economic and war conditions permit.

Probably the most effective present method of precooling pears and apples is to stack the fruit in relatively small rooms and circulate a large volume of cold air. The advantage of a small room is that after cooling has been started, it is not necessary to bring warm fruit into the same room. Where a number of small rooms are used, each can be filled in turn and cooled while others are being filled. This arrangement, however, cannot be installed without additional expense, and the cost of handling the fruit is apt to be high. For this reason cooling is usually done in larger rooms in which warm fruit is being received more or less continuously during the cooling period.

The value of any special arrangement or process for precooling is measured only by the completeness and promptness with which the fruit

is cooled. Any arrangement whereby fruit is put into a cooled room prior to final stacking in storage is loosely referred to as "precooling." It is obvious that if it does not result in quicker and more thorough cooling, it cannot be of much benefit. If such an arrangement provides only for distributing an inadequate cooling capacity over a large number of boxes during the receiving period, there is very little, if any, net gain to compensate for the extra handling. Little is gained by rushing fruit into cold storage rooms if the cooling it receives is at the expense of the fruit already there. If apples are received in a storage or precooling plant at such a rate that the compressors are required to operate continuously, further increases in receipts of warm fruit will result in partial cooling of a larger amount of fruit but less effective cooling in each box.

In many storage plants there is little danger of freezing fruit during the period of heavy receipts because of insufficient refrigeration. In certain plants, however, the full refrigerating capacity cannot be used for rapid cooling on account of the danger of freezing fruit at points near the air delivery. This freezing can be avoided and a more uniform temperature can be obtained throughout the room if there is provision for reversing the direction of air movement periodically. That is, every few hours, or as often as is necessary, the circulation will be adjusted so that air is delivered from the return ports and taken off in the delivery ports. This arrangement will provide for rapid cooling of all the fruit without danger from freezing. If such an arrangement is used, its full advantage will be obtained only if adequate refrigeration is available and sufficient volume of air is circulated.

STORAGE PERIOD

After the fruit is cooled and no more warm fruit is being received, the amount of refrigeration required is far less than during the cooling period. There are very few plants lacking in refrigerating capacity during the storage period. The problem is to maintain proper fruit temperatures in all parts of the room without danger of freezing in boxes near the air delivery or cooling coils. This uniformity of temperature depends almost entirely upon air circulation. Some heat usually enters through the walls and the fruit generates some. This must be picked up by the air and carried to the cooling coils. If insufficient air is circulating, the rise in air temperature before returning to the coils will be excessive, and some of the fruit will be exposed to the warmer air. It is usually not advisable to reduce the air circulation after the cooling period is over even though far less refrigeration is required. However, there are some plants in which the air volume is so great that little is lost by reducing it. A good way to judge whether the volume might be reduced is to check the temperature of the air entering and leaving the room. If the difference between these is less than $1\frac{1}{2}°$, some reduction in air volume might be justified. It is more economical to do this by reducing the fan speed than by restricting duct openings.

STORAGE DESIGN

The first requirement for a satisfactory cold storage plant is that sufficient refrigeration is available to cool the fruit as fast as it comes in. It is estimated that for each 1,000 packed boxes received into storage daily, 8 tons of refrigeration is required.

The next requirement is that there be sufficient air movement to distribute the available refrigeration. In blower circulating systems there should be at least 1,000 cubic feet of air per minute for each ton of refrigeration. In direct-expansion systems the air movement is most satisfactory if the cooling pipes are well distributed over the ceiling area.

It is important that the return air be taken from the room at the points of highest air temperatures. In general, these are in the upper parts of the room.

If the above conditions are satisfied, it should not be difficult to obtain good cooling.

In some plants it is difficult to get the warmest air to the return ducts. This is most easily accomplished if the returns are near the ceiling, if there is ample space between the top boxes and the ceiling, and if there are no obstructions to air movement along the ceiling. Structural members, such as girders and joists, may impede the air movement. Where the joists are ceiled and the girders are under the ceiling, the direction of air movement should if possible be parallel to the girders. On the other hand, if the joists are set on top of the girders and the joist space can be left unceiled, the direction of air movement should be parallel to the joists.

In laying out a building to be used for cold storage, the best results will be obtained if the details of the refrigerating system and those of the conveyors and other fruit-handling equipment are considered in the plans. The location of structural members, doors, and openings can then be worked out for most advantageous fruit handling and cooling. Location of girders so that they interfere with air movement can be avoided, and fruit handling processes can be fitted in with distribution of refrigeration to best advantage.

Shavings insulation is well suited to the Pacific Northwest on account of its low cost and the relatively dry climate which lessens the problem of protecting it against moisture. For use on the ground floor, pumice, of which natural deposits are found in this area, is a good insulator that is not damaged by wetting.

Whether or not to insulate partitions and interior floors depends upon the use to be made of the rooms. In most plants all the rooms are usually refrigerated at the same time. Unless there are times when rooms will be cooled individually, special provision for insulation between rooms and between floors is not necessary. Sometimes insulation used in the joist space of a ceiling is a disadvantage. If the joists run in the direction of the air movement and are set on top of the girders, the

joist spaces provide air channels over the boxes which are lost if the room is ceiled and insulated.

The design of air ducts has an important bearing on the amount of air that can be circulated by a blower. The resistance to air flow is greatest in the sections where the velocity is high and at points where the air changes velocity or changes direction. Abrupt changes in area of ducts or unrounded turns should be avoided. The inside of ducts should be free of obstructions and as smooth as possible. Where obstructions such as posts or girders cannot be avoided, it is worth while to ease the flow of air around them by installing baffles to give a streamline effect. This is particularly true at points where the air velocity is high. Large ducts are preferable because they permit delivery of the required volume of air without excessive velocities.

When a new plant is to be installed or additional equipment is being considered, it is always important to avoid excessive costs. At such times the first cost is frequently a chief consideration in deciding what equipment to purchase. Usually when the cost of a proposed job is learned, it seems excessive, and there is a tendency to look for items which may be eliminated or reduced. It is poor economy to cut down first cost by unduly limiting the cooling surface, the condenser capacity, or the size of fans and ducts. Many plants are handicapped by having too small a fan, or ducts with too much air resistance. Increasing the speed of a fan to get more air circulation does so at a cost of more power for each cubic foot circulated. For this reason it pays to install a fan having the required capacity at moderate speed. Ducts too small in cross-section or causing unnecessary turns in the air streams, build up resistances which result in high power consumption or insufficient air circulation. There are two reasons for keeping the power requirement to a minimum. First, the fan operates over a long period in the year, and the cost of power to drive the fan itself may be a large item. Second, the power used on the fan adds heat to the circulated air. This heat adds to the refrigerating load, and thus reduces the useful capacity of the refrigerating machinery. Each horsepower used on the fan puts a load of .2 to .3 h.p. on the compressor motor.

MANAGEMENT

During the cooling period many plants take in fruit faster than their equipment can cool it. As a result the fruit is not cooled to the holding temperatures until late in the fall. When this is the case, every effort should be made to use the available refrigerating equipment to the best advantage. Compressors and auxilliary apparatus need to be in good shape. Condensers should be clean and all available condenser surface used. Evaporating coils should be kept as free as possible from frost and blowers used to circulate the maximum amount of air. If, during this period, it is necessary to shut off some of the compressors to avoid local freezing while fruit temperatures are too high at some points, the capacity of the equipment is not being used to full advantage, and some means for better distribution of the refrigeration should be found. This usually may be done by improving the air circulation or increasing its volume. While ample air circulation cannot compensate for inadequate

refrigeration, it does permit maximum use of the refrigeration available.

REDUCING INITIAL FRUIT TEMPERATURE

The amount of heat that must be removed from a box of apples depends largely on how hot it is when put into storage. If the average temperature of the fruit can be reduced before storing, the load imposed on the plant by each box is lessened. Apples or pears picked in the afternoon are ordinarily hotter than those picked in the morning. Picked fruit in boxes left under the tree is considerably cooler in the morning than at evening. For these reasons, there are a number of advantages in bringing fruit to cold storage in the morning hours only. Hot fruit left loosely stacked under the trees over night may be cooler by morning than if placed in a crowded storage room. By leaving it out to cool over night, the fruit already in storage has a chance to cool faster. In short, the condition of the fruit can be improved and the number of boxes the plant can handle satisfactorily can be increased. The advantages to be gained by eliminating afternoon receipts, especially in plants of limited cooling capacity, warrants the adoption of this practice even at the expense of some difficulty in handling and hauling.

SEGREGATION OF LONG STORAGE APPLES

The Delicious variety causes the most serious problem in the Wenatchee-Okanogan area, because of its storage temperature requirements, the large tonnage of the variety, and its relatively short harvest period. If there were enough cooling capacity to cool all the Delicious apples as fast as they are harvested, it would be desirable to cool them all as quickly as possible. Since this is not the case, an attempt to cool all of this variety with equal promptness means that none of it is cooled quickly. In general, the longer a box of Delicious is to be held, the more important it is to cool it quickly. This suggests that long-storage lots of fruit should get more than an equal share of refrigeration at harvest time, and short-storage lots, less. Perhaps this can only be done by determining before harvest which lots are to be held for long storage and which are to be moved early. The fruit would then be treated accordingly. Those for long storage would be put in rooms in which the receipts would be limited to an amount that would permit fast cooling. Fruit for shipment during the harvest season or within a few days of picking would be deliberately withheld from any precooling in order to save the refrigeration for long-storage lots. Apples for intermediate shipment would be cooled as quickly as possible without penalizing the long-storage lots. This, of course, involves more planning before harvest than does a procedure whereby all Delicious in storage, but such planning would be justified by the improved condition of late shipments. It should be emphasized that such sacrifice in cooling early shipments is desirable only when limited capacity prevents prompt cooling of the entire Delicious crop.

SEGREGATING TO AVOID SOFT SCALD

Development of soft scald in Jonathans and other varieties, including Winesaps, is sometimes induced by a quick reduction in fruit tempera-

ture to 32° after the fruit is somewhat advanced in maturity or is
delayed after picking before going into storage. When such delays
are unavoidable, the disorder may be avoided by holding at 36° or
above for the first few weeks of storage. Considerable soft scald
appeared in Winesaps for the 1941 crop, and it was probably largely
due to a low storage temperature after the fruit had been held in the
orchard or in common storage. When it is impossible to get these
varieties into cold storage promptly, they should be cooled only to a
moderate temperature and segregated for early disposal. It is there-
fore highly desirable to avoid putting them in the same room with De-
licious which should be held at 30° to 32°. Storage in separate rooms
in which the temperature can be controlled independently is desirable.
The fruit will not keep so long at this higher temperature, but the
risk from soft scald will be avoided.

PLANT OPERATION

A cold-storage plant represents a relatively large investment in
machinery and construction. Such investment can be justified only if
it increases the value of the fruit stored. The value of a plant in
maintaining fruit condition is largely determined by the way it is
operated. Even the best designed plant with automatic equipment needs
more or less continuous attention to insure the best results.

CORE TEMPERATURE

In order to make the best use of a plant, it is important to know what
temperatures are being maintained. One or two thermometers for show-
ing aisle air temperatures do not indicate the performance of a plant.
An operator needs to know core temperatures of the fruit, especially
in parts of the room where cooling is difficult. Periodic observations
of fruit temperatures will indicate to an operator what methods of
stacking and air distribution give best results and will show what parts
of the room need special attention. Reliable thermometers are necessary
for this purpose, and an investment in equipment for securing accurate
records of temperature in all parts of a storage is very worthwhile.

Frequently when actual fruit temperatures are measured, the results are
disappointing. If they are, it is sometimes possible to improve con-
ditions markedly with little cost or inconvenience. In any case, it is
to an operator's advantage to know just how quickly he can cool a load
of apples and how uniform he can hold the temperatures after they are
cool.

AMMONIA PRESSURES

Routine observation of the gage pressures on the refrigeration equipment
should be made. If the suction pressure goes too low or the head
pressure too high, these are signs that the system needs attention.
Ordinarily suction pressures below 20 to 25 pounds indicate that the
cooling coils are not picking up heat as readily as they ought to. Head
pressures over 160 to 170 pounds indicate lack of sufficient cooling in
the condenser. These limits depend upon the kind of system used, but
the cause of any unexpected changes in pressure should be found and
corrected. If the pressures are normally outside the above limits, the

possibility of making adjustments or changes in the installation should
be investigated in order to reduce power consumption and get more re-
frigeration. Suction pressures as high as 35 to 40 pounds and head
pressures as low as 100 to 120 pounds can be obtained under favorable
conditions. Pressure gages should be checked for accuracy occasionally
since they may go out of adjustment after long use.

STACKING BOXES

It is customary to paint lines on the floor of storage rooms to indicate
the placing of rows of boxes. Such lines facilitate even stacking. It
is important to maintain the space between rows at all points. A uni-
form spacing of 2 inches between rows has been found in tests to be
practically as effective in permitting cooling as spacing up to 5 or 6
inches, if there is sufficient head room between the boxes and the ceil-
ing. Careless stacking, however, in which some boxes in one row touch
or approach those in another row, restricts air movement and retards
cooling. It has been found that a spacing of about 3 inches is needed
in order to release box trucks when trucking fruit into rows, and con-
venience in trucking has regulated spacing in most storage houses. To
overcome slight irregularities in stacking, 3 inches may be considered
a satisfactory spacing for the bottom boxes. The rows should be laid
out so that the general direction of air movement is along the rows of
boxes instead of across them.

When fruit is stacked too close to the ceiling, air movement is re-
stricted and cooling cannot be evenly distributed. No rule has been
established on the minimum space required over the boxes to permit good
circulation, but it is good practice to leave a space of several inches
even if the ceiling is free from girders or other obstructions.

In large rooms warm apples may be brought in over a long period. This
means that fruit which has been in the room for some time and should be
cold is sometimes warmed up by incoming fruit. This effect is unavoid-
able in some rooms but by judicious stacking, it can be kept to a mini-
mum. In some cases it is possible to stack the first fruit brought in
nearest to the air discharge ports so that after it is cooled it is
not exposed to air coming off of warm fruit brought in later. In plants
that have two levels with a slotted floor between, it is good practice
to load the lower floor first so that fruit already cooled is not sub-
jected to warm air rising from warmer fruit below.

AIR CIRCULATION

In most storage rooms the air circulation is planned so that the primary
air movement is over the tops of the boxes and through aisle spaces.
The cooling in the interior of the stacks is accomplished partly by
secondary or convection currents up and down the spaces between boxes.
This cooling is effective only insofar as the warm air which rises to
the ceiling is moved away and replaced by colder air. The reason for
leaving a reasonable amount of space overhead is to permit sufficient
circulation for carrying off the heated air. If the space is limited,
there is a tendency for the air to move along aisles or unfilled chan-
nels in preference to the ceiling space.

If the primary air circulation can be forced to move through the spaces between stacks, more rapid cooling can be accomplished. Reducing the space over the boxes will tend to move more of the primary circulation through the spaces, but it will also divert more of it through aisles or other open channels; and unless such channels are avoided, loading close to the ceiling or putting baffles across the ceiling to force more air into the box spaces may result in moving most of the air through the aisles where it is least effective for cooling.

For storage rooms in which relatively slow cooling will be tolerated, the type of circulation which provides for flooding the ceiling space with moving air and depends upon convection to cool the interior of the stacks will provide fairly uniform temperatures throughout the room with a minimum of care in laying out the loading arrangement. If, in order to hasten cooling, the primary air is forced through the space between boxes, the ceiling space is sacrificed, and the natural convection from the ceiling space down into the stacks is greatly reduced, but the forced circulation among the boxes gives better cooling on account of the higher air velocity. It will be seen that if the convection cooling is sacrificed by reducing the ceiling space, it is important that forced circulation take its place. Otherwise the effectiveness of cooling will be reduced instead of increased. For this reason, if an attempt is made to force air through the box spaces by cutting down circulation over the load, great care must be exercised in arranging the boxes. Uniform spacing becomes even more important and air channels which will permit diversion of air around the stacks of boxes must be avoided. Precooling rooms in which these conditions are met provide much faster cooling than rooms in which convection is depended upon for cooling the interior of the stacks.

FROSTED COILS

Accumulation of heavy layers of frost on cooling coils should be avoided. Pipes or finned coils need to be defrosted frequently to get the most from a cooling system. Disposal of the ice and water from defrosting may be a problem in direct expansion plants but removal of the frost is important especially during the cooling period.

BRINE TREATMENT

In brine-spray plants the frost is washed off with brine. The water which would otherwise be on the coils is continually diluting the brine making it necessary to drain off some brine at intervals and add more salt. The brine should not be any stronger than is necessary to prevent accumulation of ice. One objection to brine spray systems is that upon exposure to air, the brine tends to become acid. Unless this tendency is checked, the particles of brine carried by the air are very corrosive and may damage any metal with which they come in contact. The brine may be treated with a chemical to retard this corrosive effect. The instructions regarding such treatment, which are furnished by the ice machine company installing the equipment, should be followed carefully. Such instructions should be requested if they have been lost or forgotten.

CONDENSER CARE

The water used in condensers leaves a deposit on the pipes which inter-feres with heat transfer if allowed to accumulate. The water tubes of a condenser should be examined at least once each year preferably prior to the harvest season, to make sure they are in good condition, and if necessary given a good cleaning.

CARE OF COMPRESSOR

The compressor and other machines, including motors and pumps, need care-ful attention. Instructions furnished by the ice machinery companies should be kept in the engine room and referred to frequently. These instructions should cover operation of the particular machines in the plant. Carelessness in operation or failure to observe the recommended routine may prove expensive in repair or replacements.

CONTROLS

There are numerous types of controls used in various plants. The auto-matic parts of the equipment usually depend upon changes in temperature or pressure, or are controlled by clocks. It will pay to become familiar with the principle of operation of each item involved in automatic con-trol.

FANS AND DUCTS

In air circulation systems, the fan size and speed are usually selected to deliver a certain volume of air against an estimated resistance in the system. By keeping the resistance as low as possible, a maximum volume of air will be circulated. Frequently a fan will be found to have a film of dirt and grease accumulated on the blades and interior. This interferes with the air flow and should be cleaned off occasionally. In operating the dampers and openings in ducts, they should be as wide open as will permit the desired air distribution. In making adjustments the ports requiring more air should be opened to full capacity in prefer-ence to closing down dampers or openings at other points. When the de-livery temperature of the air is too low, ports should not be closed down to prevent freezing. The temperature of the air should be raised instead, and as much volume as possible permitted to circulate through the room. In many plants there is too little air circulation. This results in high temperatures in parts of the room and sometimes an attempt is made to correct this by lowering the delivery air tempera-ture. If this becomes too low for safety, closing down the openings to prevent freezing aggravates the condition instead of improving it.

FREEZING NEAR COILS

In direct expansion rooms, the boxes nearest the coils sometimes become too cold even though other fruit in the room may be too warm. Frequently this happens because the boxes themselves are radiating heat directly to the coils, even though the air next to them may be above the freezing point. In this case, increased air circulation may keep the boxes from getting too cold or it may be necessary to put a shield between the boxes

and the pipes. This shield is not for deflecting the air but is to
prevent direct radiation, that is, to stop the "shining" of heat from
the box to the cold surface of the pipes. This "shining" or radiation,
takes place regardless of the temperature of the air between the box
and the pipes.

KEEPING EQUIPMENT BALANCED

To get the best results from a plant, the various steps in mechanical
removal of heat need to be balanced. That is, the heat picked up in
the room must be transferred from the fruit to the air, from the air
to the cooling coils, from the coils to the compressor, and from the
compressor to the condenser, where it is discharged to the cooling
water. If in one or more of these steps the quantity of heat that can
be transferred is unduly restricted, the equipment performing the other
steps cannot be worked to its greatest capacity. The condenser is doing
its part if the head pressure is not excessive, and the cooling coils
are not unduly limiting the capacity of the plant if the suction pressure
is well up. It is less simple to know if the air circulation system is
in balance with the rest of the equipment. During the cooling period
when the refrigerating equipment is operating to full capacity, the
volume of air circulation may be considered in balance if the tempera-
ture difference between delivery and return air does not exceed 10°.
A lower split is desirable but if it is greater than 10° an increased
volume of air circulation will be found beneficial. As the load is
cooled down and as less warm fruit is brought in, the split will decrease
and should reach 1° to 2°. If, after the fruit temperatures become about
stationary, the split exceeds $1\frac{1}{2}^{\circ}$ this is an indication of insufficient
air volume. During this later period further cooling is not required,
but it is necessary to maintain uniform temperatures throughout the
room. Uniformity of temperatures depends first on an adequate volume of
air. If the volume is sufficient, as indicated by the split between
delivery and return, and temperatures in some parts of the room are still
too high, the air is not being distributed to best advantage. This may
sometimes be corrected by readjusting the delivery or return openings,
giving special attention to increasing the volume of air entering the
return ducts near the points of highest temperature.

Average Freezing Temperatures

of Various Fruits

Commodity	Degrees Fahr.
Apples	
Delicious	28.36
Jonathan	28.35
Winesap	28.24
Pears	
Bartlett hard ripe	28.5
Soft ripe	27.8
Anjou hard ripe	26.9
Soft ripe	27.2
Cherries	
Bing — mature (black)	24.1
Bing — immature (bright red)	25.3
Sour	28.0
Peaches	
Elberta	29.7
J. H. Hale	29.6

Appendix No. 1

Approximate Refrigeration Required

for

Delicious Apples

For receiving 1000 boxes daily and cooling fruit to 32° F.
in seven days. (Allowance for open doors, workmen, motors,
etc., may increase this requirement by 15 or 20%.)

Initial Fruit Temperature	Tons of Refrigeration
55	4.9
65	6.9
75	8.8
85	10.8

For holding, after reaching 32° each 1000 boxes requires about
.07 T. 1 ton of refrigeration will care for about 15,000 boxes.

Appendix No. 2

Space Required by Standard Boxed Apples

	Packed	Loose
Height	1.0 Feet	.91 Feet
Width	1.13	1.03
Length	1.63	1.63
Length required for 3" spacing	1.88	1.88
Net Cubic Feet per box, 3" spacing	2.12 Cu. Ft.	1.93

In estimating gross space required in a storage room, allowance must be made for aisle space, conveyors, wall ceiling clearance, duct or piping space, and other space not actually usable for boxes. Making these allowances, a gross space of 2.5 to 2.7 cubic feet per box is sometimes used.

Appendix No. 3

Maximum Relative Humidity of Air

If air is chilled to: and its temperature then raised to:

	24°	26°	28°	30°	32°	34°	36°	38°	40°
16°	68	62	57	52	47	43	40	37	33
18°	75	68	62	57	52	48	44	41	36
20°	83	76	69	63	57	53	49	45	39
22°	91	83	75	69	63	58	54	49	44
24°	100	91	83	76	69	64	59	54	48
26°		100	91	83	76	70	64	59	53
28°			100	91	83	77	71	66	58
30°				100	91	84	78	72	64
32°					100	92	85	79	70

Appendix No. 4

	SODIUM CHLORIDE BRINE		
Specific Gravity	Pounds salt in 100# of Brine	Freezing Point	Density Pounds per Gallon
1.00	0	32.0	8.33
1.02	2.8	29.1	8.50
1.04	5.5	26.0	8.67
1.06	8.2	22.7	8.84
1.08	10.9	19.0	9.00
1.10	13.5	14.9	9.17
1.12	16.1	10.4	9.34
1.14	18.6	5.4	9.50
1.16	21.1	-0.3	9.67
1.18	23.5	-3.6	9.84
	Appendix No. 5		

Temperature of Liquid Ammonia
at
Various Gage Pressures

Gage Pressure	Temperature °F.	
0	-28	
5	-17	
10	- 8)	
15	- 0)	
20	5)	
25	· 11)	Usual range of low side
30	17)	
35	· 21)	
40	· 26	
50	34	
75	50	
100	63)	
125	75)	
150	84)	Usual range of high side
175	93)	
200	101)	

Appendix No. 6

Capacity and Power for Typical Ammonia Compressors
of various sizes
when operating at 155# Condenser Pressure and 20# Suction Pressure

Cylinder Size Inches	Displacement per Revolution Cu. Ft.	Speed RPM	Typical Refrigerating Capacity at 155# condenser Pressure and 20# Suction Tons	Typical Power Requirement at 155# Condenser Pressure and 20# Suction Pressure H.P.
3 x 3	.024	400	2.1	3.5
3½ x 3½	.039			
4 x 4	.058	375	4.7	7.1
4½ x 4½	.083			
5 x 5	.113	360	8.9	13.4
5½ x 5½	.150			
6 x 6	.196	360	15.6	21.8
6½ x 6½	.249	360	20	28
7 x 7	.312			
7½ x 7½	.383	360	31	43
8 x 8	.465	360	39	53
8½ x 8½	.557			
9 x 9	.662	300	48	63
9½ x 9½	.779			
10 x 10	.909	300	67	87

Appendix No. 7

HP Per Ton for Typical 6x6 Ammonia Compressor

Cond. Pres.	Suction Pressure				
	10	20	25	30	35
85	1.30	.90	.77	.66	.56
105	1.42	1.04	.90	.79	.68
125	1.62	1.28	1.03	.91	.82
145	1.75	1.33	1.17	1.03	.93
165	1.94	1.47	1.31	1.17	1.05
185	2.12	1.60	1.44	1.30	1.17
205	2.29	1.76	1.57	1.42	1.29

HP Per Ton for Typical 9x9 Ammonia Compressor

	Suction Pressure				
	10#	20#	25#	30#	35#
85#	1.20	.84	.71	.61	.52
105#	1.32	.97	.84	.73	.64
125#	1.50	1.11	.97	.86	.77
145#	1.67	1.25	1.10	.98	.88
165#	1.83	1.39	1.23	1.11	1.00
185#	2.00	1.53	1.36	1.23	1.11
205#	2.17	1.67	1.50	1.36	1.24

Appendix No. 8

REFERENCES ON COLD STORAGE

Text Books and Discussions
of
Refrigeration Principles and Apparatus

1. Refrigeration - Moyer and Fittz

2. Principles of Mechanical Refrigeration - MacIntire

3. Refrigeration in the Handling, Processing, and Storing
   of Milk and Milk Products - Bowen. Miscellaneous
   Publication 138 US Department of Agriculture.
   For sale by Superintendent of Documents, Washington,
   D. C.--10 cents.

4. Instructions for the Operation and Maintenance of Refrigera-
   ting Plants - United States Navy, Bureau of Engineering.
   For Sale by Superintendent of Documents, Washington,
   D. C.--30 cents.

Handbooks of Specific Information Including Tables of Data

1. Refrigerating Data Book, Volume 1 - American Society of
   Refrigerating Engineers.

2. Fan Engineering - A Handbook on air; its movement and distri-
   bution - Buffalo Forge Company, Buffalo, N. Y.
   (Revised) 1938.

Discussions and Data
on
Cold Storage Operation and Fruit Requirements

1. Refrigerating Data Book, Volume II - American Society of
   Refrigerating Engineers.

2. Commercial Storage of Fruits, Vegetables, and Cut Flowers
   Rose, Wright, and Whiteman. Circular No. 278 - 1941
   US Department of Agriculture. For sale by the
   Superintendent of Documents--10 cents.

3. The Freezing Temperatures of Some Fruits, Vegetables, and
   Florist Stocks - Wright. Circular No. 447 - 1937.
   Available from Bureau of Plant Industry, Washington,
   D. C.

4. A Survey of Fruit Cold Storage Plants in Central Washington
   --Dana. Engineering Bulletin No. 26. Engineering
   Experiment Station, State College of Washington,
   Pullman, Washington.

5. Apple Scald and its Control
        Brooks and Fisher. USDA Farmer's Bulletin 1930.

6. Soft Scald and Soggy Breakdown in Apples
        Brooks and Harley. Journal Agr. Res. Volume 49
        No. 1934.

7. The Ripening, Storage, and Handling of Apples
        Magness, Diehl, Haller and Graham. US Department
        of Agriculture, Bulletin 1406 - 1926.

8. Apple Harvesting and Storage in British Columbia
        Britton, Fisher and Palmer. Dominion of Canada
        Department of Agriculture. Publication 724 - 1941.

9. Handling Apples from Tree to Table.
        D. F. Fisher, U. S. Department of Agriculture.
        Circular 659.